US Army Corps of Engineers
Waterways Experiment Station

AD-A275 317

Technical Report REMR-HY-9
December 1993

2

Repair, Evaluation, Maintenance, and Rehabilitation Research Program

Design Criteria for Lateral Dikes in Estuaries

by R. C. Berger, M. P. Alexander
Hydraulics Laboratory

Approved For Public Release; Distribution Is Unlimited

Prepared for Headquarters, U.S. Army Corps of Engineers

The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

Repair, Evaluation, Maintenance, and Rehabilitation Research Program

Technical Report REMR-HY-9
December 1993

Design Criteria for Lateral Dikes in Estuaries

by R. C. Berger, M. P. Alexander
Hydraulics Laboratory

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

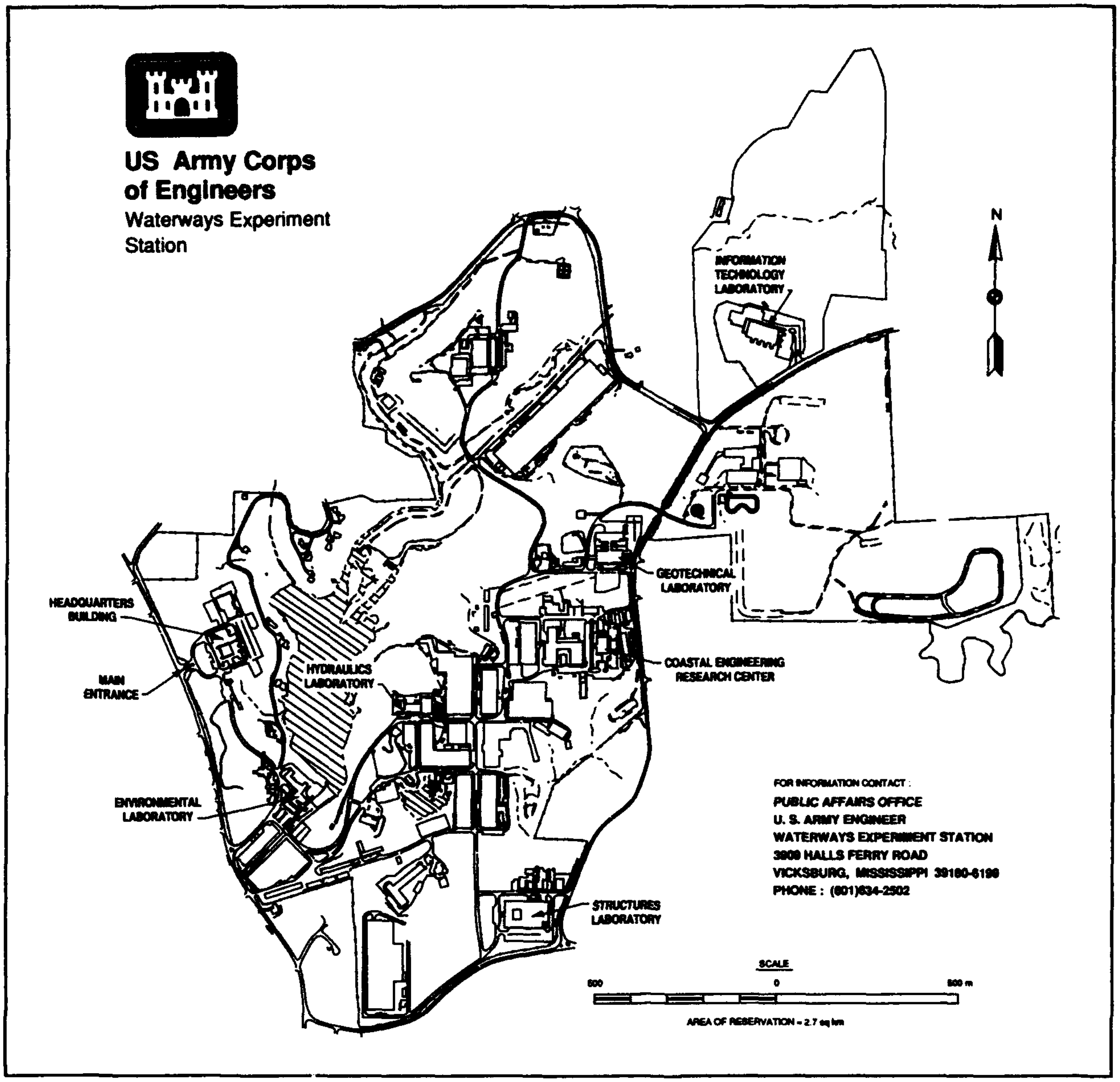
Accesion For		
NTIS CRA&I	X	
DTIC TAB	☐	
Unannounced	☐	
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Civil Works Research Work Unit 32655



Waterways Experiment Station Cataloging-in-Publication Data

Berger, Rutherford C.
Design criteria for lateral dikes in estuaries / by R.C. Berger, M.P. Alexander ; prepared for U.S. Army Corps of Engineers.
37 p. : ill. ; 28 cm. — (Technical report ; REMR-HY-9)
Includes bibliographical references.
1. Dikes (Engineering) — Design and construction. 2. Hydraulic engineering. 3. Embankments. 4. Channels (Hydraulic engineering) I. Alexander, Michael P. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Repair, Evaluation, Maintenance, and Rehabilitation Research Program. V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; REMR-HY-9.
TA7 W34 no.REMR-HY-9

PREFACE

The work described in this report was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Hydraulics Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed during the period October 1987 - September 1988 under Work Unit 32655, "Estuarine Channel Maintenance by Training Structures," for which Mr. R. C. Berger, Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), was Principal Investigator. Mr. Dave Wingerd (CECW-EH) was the REMR Technical Monitor for this work.

The information in this report was also sponsored by the former Improvement of Operations and Maintenance Techniques (IOMT) research program, Work Unit 32350, "Estuarine Channel Maintenance by Training Structures," sponsored by HQUSACE.

The REMR Directorate of Research and Development Coordinator in HQUSACE was Mr. William N. Rushing (CERD-C), and members of the REMR Overview Committee were Mr. James E. Crews (CECW-O), Chairman, and Dr. Tony C. Liu (CECW-EG). The REMR Program Manager was Mr. William F. McCleese (CEWES-SC-A), and the Problem Area Leader was Mr. Glenn A. Pickering, Chief, Hydraulic Structures Division, HL. Mr. Robert F. Athow, Estuaries Division, HL, was IOMT Program Manager.

This report was written by Messrs. R. C. Berger and M. P. Alexander, both of the Estuaries Division, under the supervision of Messrs. Frank A. Herrmann, Jr., Chief, HL; Richard A. Sager, Assistant Chief, HL; William H. McAnally, Jr., Chief, Estuaries Division; and Messrs. Robert F. Athow and William F. McCleese, IOMT and REMR Program Managers, respectively.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

CONTENTS

LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres

DESIGN CRITERIA FOR LATERAL DIKES

IN ESTUARIES

PART I: INTRODUCTION

Background

1. Dikes have long been used as flow training structures in US waterways. Figure 1 shows a cross section and plan view of a typical impermeable stone dike. Dikes can be designed for various purposes, including bank stabilization, material confinement, and navigation maintenance. Designing dikes for the purpose of navigation maintenance is addressed in this report. Design procedures and considerations were developed for estuarine channels in particular.

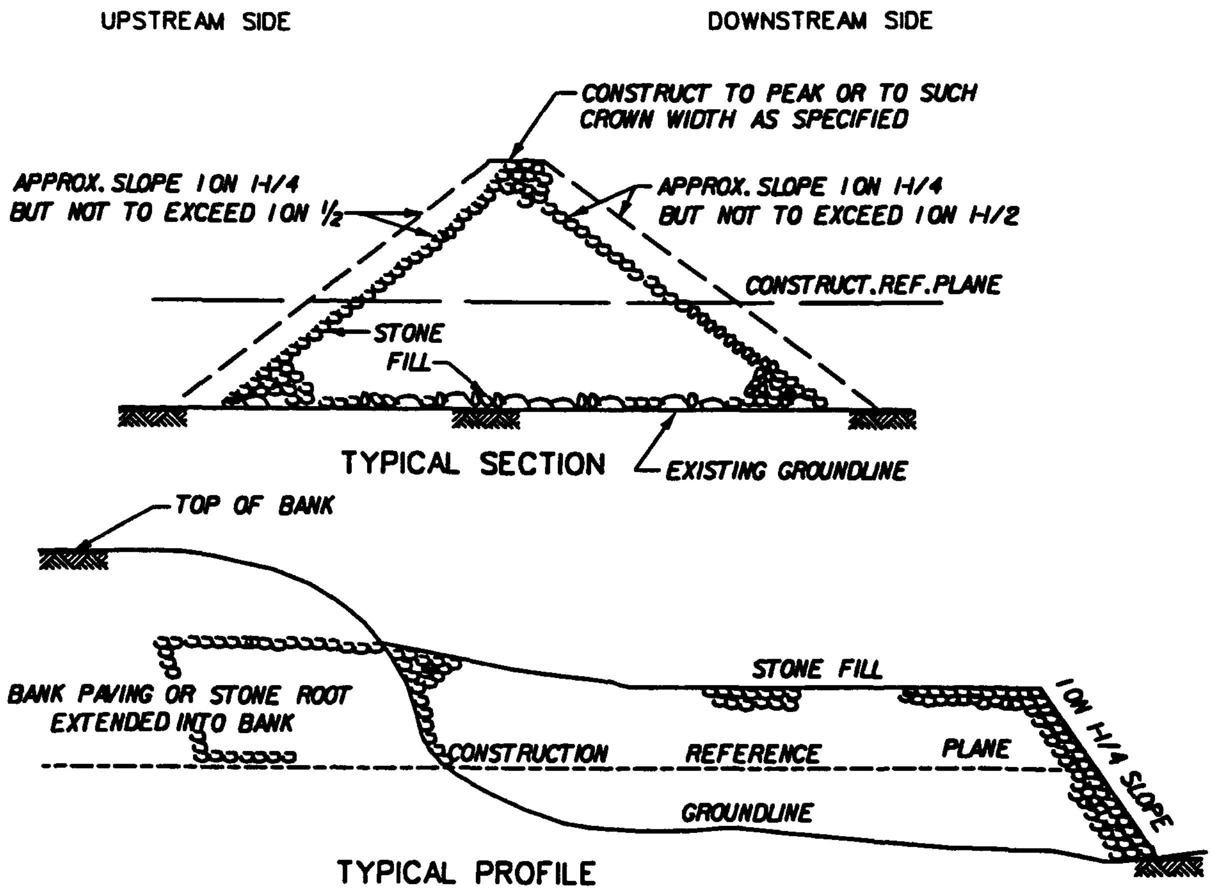


Figure 1. Impermeable dike schematic

2. Maintenance dredging at regular intervals is common practice in most navigation projects. However, some channel reaches are self-maintaining in

that sediment supplied to these reaches can be transported through the reach by natural current velocities. Self-maintenance can be effected in an aggrading channel reach by reducing the cross-sectional area with lateral dikes, thereby increasing the flow velocity in that channel section.

3. Dike length can be based, with a great deal of confidence, on the length of existing dikes in reaches that are experiencing little or no maintenance dredging. There are currently no analytical procedures for designing the amount of contraction. A logical guideline from early riverine works was to examine the channel in question and ascertain width and cross-sectional area from self-maintaining reaches. Then, these values could be used to determine the amount of contraction for any aggrading section of channel within the same hydraulic regime.* A rule of thumb from past projects has been to design dike lengths conservatively and allow for further constriction later, if required. The goal is to maintain the channel without causing rapid erosion of the opposite bank or velocities that are too high for navigation. General design cautions are as follows:

- a. Too little contraction will not affect maintenance. However, the presence of the structure might stabilize bank erosion and channel alignment, indirectly reducing project maintenance.
- b. Too much contraction can divert flow to other channels or directions, causing insufficient transport velocities and aggradation problems. If flow is contained, velocities may be too high, inducing local scour and subsequent deposition downstream. Velocities may also be too high for safe navigation.

4. When the amount of constriction has been estimated, other design parameters such as spacing and dike field energy loss significantly affect the resulting channel velocity. In an estuary, the velocity attained in a constricted reach is more difficult to estimate than in a riverine environment. In rivers, a steady-state ratio of the discharge before constriction divided by the newly constricted area yields a reasonably accurate estimate of velocity. In a tidal environment, the flow is unsteady. The discharge rises gradually to a peak, slows, and then reverses. The magnitudes and durations of the flood and ebb are dependent upon hydrology, astronomical tides,

---

* G. B. Fenwick, ed. 1969. "State of Knowledge of Channel Stabilization in Major Alluvial Rivers," Technical Report No. 7, prepared for US Army Corps of Engineers Committee on Channel Stabilization by US Army Engineer Waterways Experiment Station, Vicksburg, MS.

wind-induced tides, and the geometry of the estuary. To predict the impact of a dike field on the flow, numerical modeling is usually required, which, in turn, often requires an estimate of the energy losses due to the dikes. An aggrading channel section normally requires a series of lateral dikes, and dike spacing becomes a major design consideration.

5. Dike length can be adjusted in the field more easily and more cost effectively than spacing. Rule-of-thumb dike spacing practices developed for river stabilization projects over the years have been carried over into channel contraction works. Stone or pile dikes were spaced from 1 to 2 or more times the length of the next upstream dike.* Most spacing ratios were developed for a particular waterway and are not verified elsewhere. The most difficult problem in dike design is determining spacing. If spacing can be properly determined at an early stage in the design, the designer can more readily determine the most cost-effective system. General design cautions for spacing are as follows:

a. If spacing is too close, the additional dikes will result in an over-designed, more costly control system. Conservative spacing practice will not by itself hinder project performance. However, minimizing the number of dikes constructed with optimum dike field performance is an important economic decision.

b. If the spacing is too far apart, control of the channel width between the dikes will not be possible without as much or more predike construction maintenance dredging. Constructing additional dikes in between too widely spaced dikes can achieve channel width control, but this would be an expensive corrective measure.

6. The research reported herein investigated relationships between some of the dike design variables. The subject work resulted in a framework that relates a selected dike spacing and number of dikes to energy losses. The dike spacings resulting in the lowest energy losses were those observed with the most uniform flow fields. Poorer spacing arrangements resulted in flow fields containing more energy captured in rotating flow. Therefore, minimal energy losses can indicate the most efficient and effective dike spacings. This research also resulted in a degree of dike field arrangement and orientation insight. The spacing framework was developed for use with numerical model evaluations for optimizing dike spacing. Dike field energy losses are

* Fenwick, op. cit.

also used to produce a reasonable estimate of postproject channel velocity and water level.

Purpose

7. The primary purpose of this report is to present lateral dike spacing design steps for use within the overall dike planning and design process. Guidelines were based on laboratory data and apply to lateral dikes constructed for navigation maintenance, particularly in estuaries. Secondary analyses evaluated dikes on both sides of a test channel section. Finally, plans with angled entrance dikes were included as a possible means of allowing a smoother flow transition through the dike field.

Scope

8. The remainder of this report is divided into four parts. The laboratory tests are described in Part II. Dike spacing design guidance was developed and presented in Part III, and Part IV describes angled and opposing dike test evaluations. Finally, Part V summarizes this research and recommends additional study.

PART II: DESCRIPTION OF TESTING

9. Two series of tests were completed during this study. Series I plan tests (Figure 2) were designed to investigate the effects of velocity and head loss over a range of dike spacing to dike length ratios. Series II tests (Figure 3) were designed to investigate flow field reaction to opposing dikes. Various configurations of opposing dikes were tested. Series II tests also evaluated using angled dikes at the beginning of a dike field to reduce energy loss and provide a smoother flow field transition. Angled dikes were included at both ends of the test section since flow reversals occur in estuaries. Plan ratios, S (dike spacing/dike length), were as follows:

Dike Spacing/Dike Length Ratios

Series I		Series II	
Plan	S, Spacing/Length Ratio	Plan	S, Spacing/Length Ratio
1A*	—	1CA	5
1B	12.5	1CB**	2.5
1C	5	1CC**	2.5
1D	2.5	1CD†	5
1E	1.25	1CE**,†	2.5

* Single dike test
** Opposing dike plan
† Includes angled entrance dikes

10. Each plan was tested in the flume facility with three different flow rates: 1.0, 2.0, and 3.6 cfs.* The test section was not patterned after a particular prototype, but was designed to mimic natural conditions with high Reynolds numbers and fully turbulent flow. Test section dimensions are shown in Figures 2 and 3. All test dike lengths were 2 ft long. The angled dikes were placed at 45 deg from the test section sidewall, and they also extended a lateral distance of 2 ft into the flow. The dike length/channel width ratio of 1/5 was designed to avoid opposite-bank effects in the flume test facility. Surface current patterns were studied, and dike-induced

* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

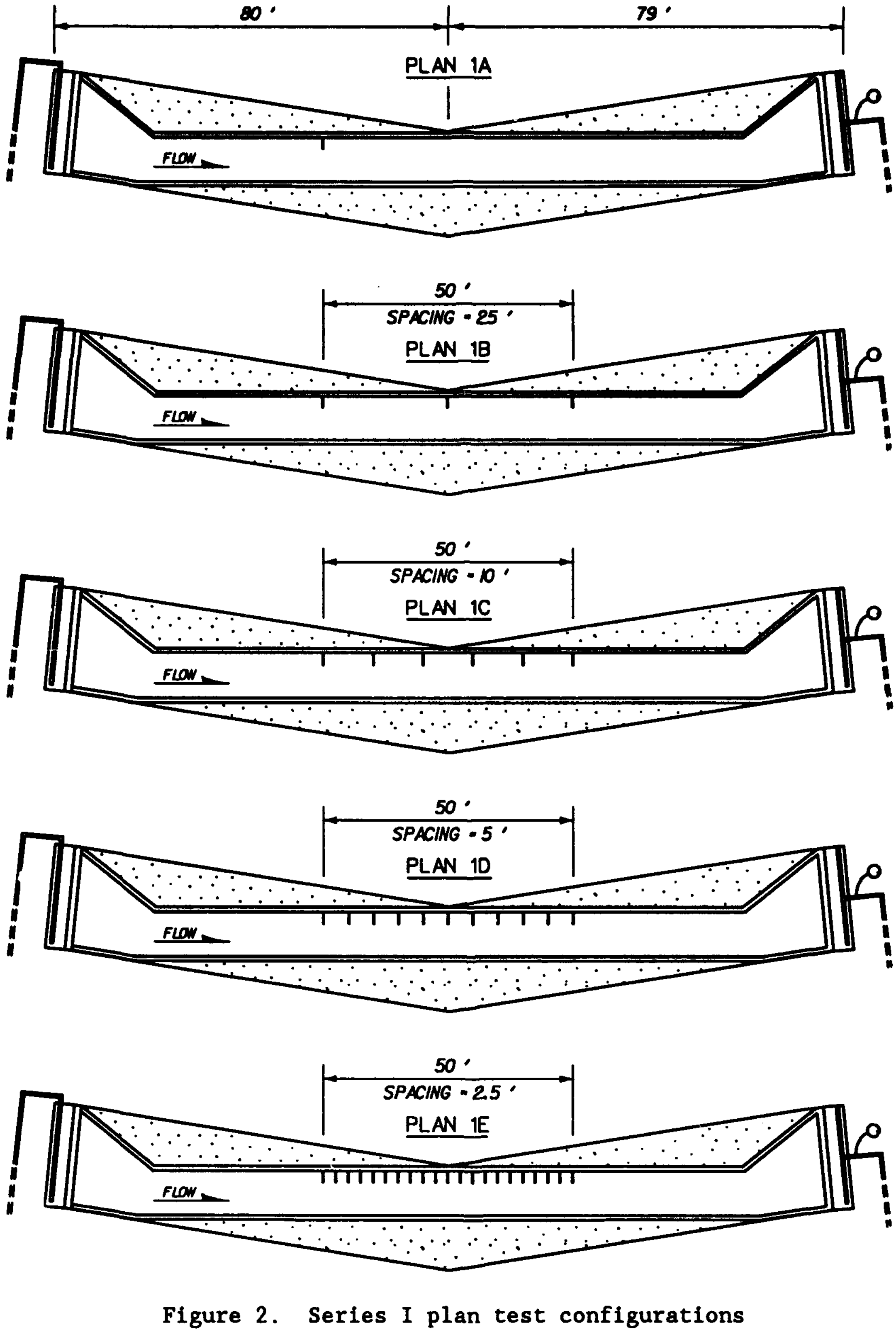


Figure 2. Series I plan test configurations

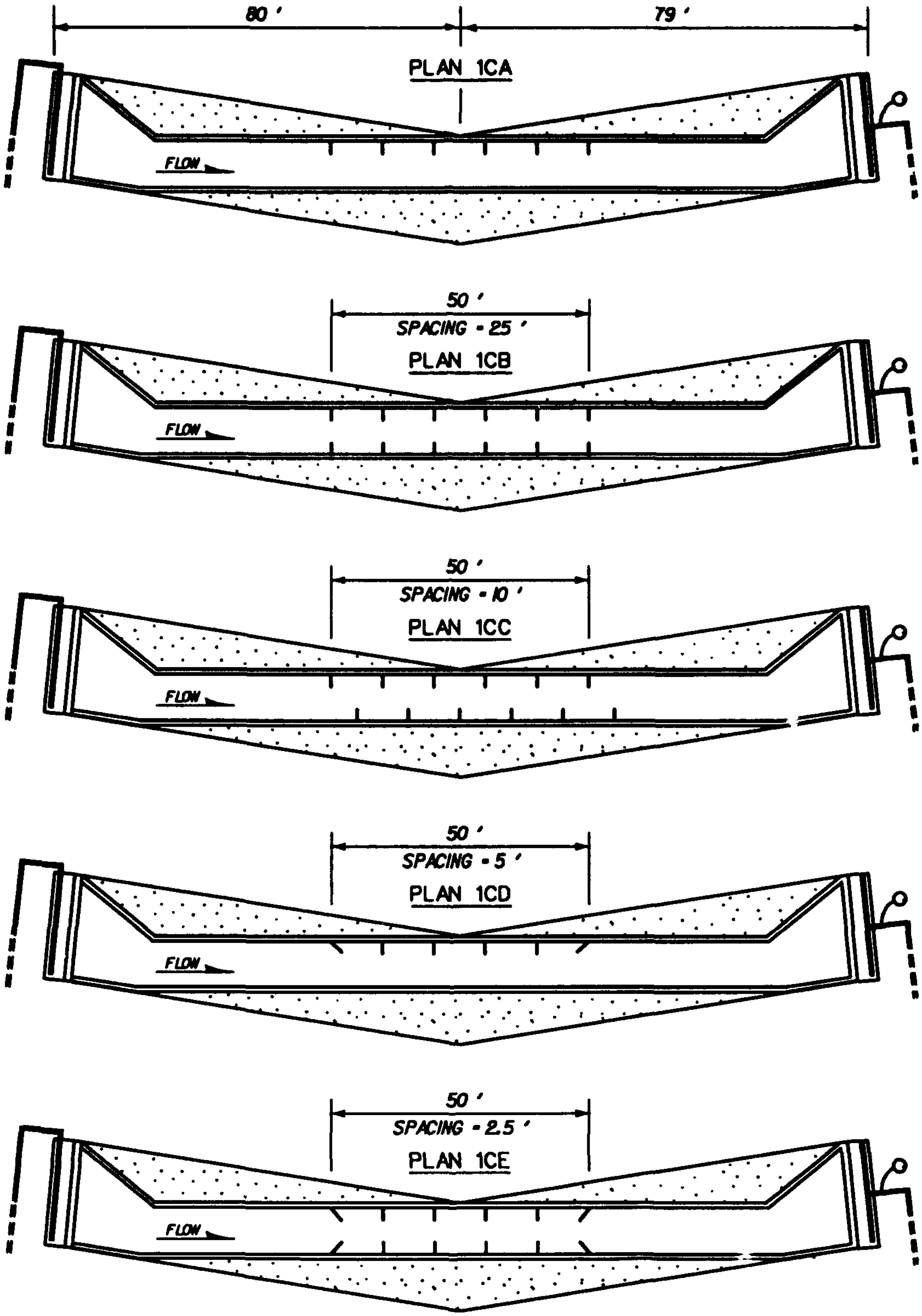


Figure 3. Series II plan test configurations

flow patterns did not reach the opposite side of the flume. Certain Series II plans, however, were designed to study the combined effects of opposing dikes.

11. A flume facility cannot duplicate the interaction of all variables in a natural waterway. Water depths were not varied in the subject tests, and the fixed bed and walls did not allow bed form or sediment transport investigations. However, several important design parameters were related to develop a dike spacing framework within tidal waters. They included the following:

a. Flow patterns. Form and drag resistance compose the bulk of preconstruction energy losses. In the flume facility, losses due to bottom and side friction were subtracted prior to evaluating the dominant dike-induced energy losses. An indication of the eddy turbulence was observed from the surface current patterns. Surface current patterns were photographed for study using a bright flash and floating confetti.

b. Water level change. Water level change is a preconstruction condition in estuaries that will change with any significant flow modification such as dike construction. Water level changes were plotted and analyzed for each plan tested.

c. Channel velocity. Increasing channel velocities within a uniform flow field is the desired effect for a channel constriction dike project. Normalized flume facility velocities along the test section center line and quarter-width points were plotted and analyzed.

12. The preceding design parameters were investigated for each plan and for each of the three flow rates. The water level change data and test channel section velocities are described and included in Appendix A. A complete set of data for the subject flume tests can be found in Ashley and Brogdon.*

* John S. Ashley and N. J. Brogdon. "Lateral Dike Design Studies for Channel Maintenance: Data Summary and Presentation" (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

PART III: DESIGN GUIDANCE FROM SERIES I TESTS

13. Figure 4 shows the surface current patterns for each Series I plan. In the flume facility, the higher spacing ratios allowed flow patterns to develop more pronounced turbulence between dikes, generally resulting in multiple-eddy formations. The eddy patterns for the smaller spacing ratios tested (2.5:1 and 1.25:1) appeared singular, and the shorter streak lines indicated lower rotational velocities. As spacing ratios became larger, double- and then multiple-eddy formations developed, resulting in greater rotational velocities and higher energy losses.

14. The sequence of dike spacing ratios in the Series I tests was sufficient to develop graphical relationships between energy loss and the plans tested. Most of the energy loss in the flume was a result of the dike field form, and a high energy loss indicates a less uniform flow field. A better flow distribution in which channel velocity maintains a uniformly high level is indicated by a lower energy loss for a particular dike spacing. Figure 5 relates the energy loss coefficient k to the number of dikes present. The spacing ratio S is also indicated in Figure 5. The figure refers to the total k, or the energy loss coefficient for the entire dike field. The larger, multiple-eddy current patterns (Figure 4) resulted in the largest energy loss coefficients. A suggested optimum range of spacing ratios is shown in Figure 5. This spacing range corresponds to the energy loss coefficients for the number of dikes between the spacing ratios of 2.5:1 and 5:1. Surface current patterns indicated uniform velocity flow fields over this range of spacings. From Figure 5, a rapid decrease in energy loss was observed from the highest spacing ratios tested down to the 5:1 ratio. The more confined, single-eddy patterns resulted in the least energy loss. Energy loss was minimized within the suggested range; and based on the subject tests, the comparatively small decrease in energy loss obtained with spacing ratios less than 2.5:1 would not be feasible for prototype construction.

15. Reducing the area of an estuarine channel may change the tidal range along with any desired increase in velocities. Designing lateral dikes for estuarine channels requires modeling each individual training works plan to determine resulting velocities in conjunction with tides. Additional considerations may include the effects of changing water levels and durations at respective levels.

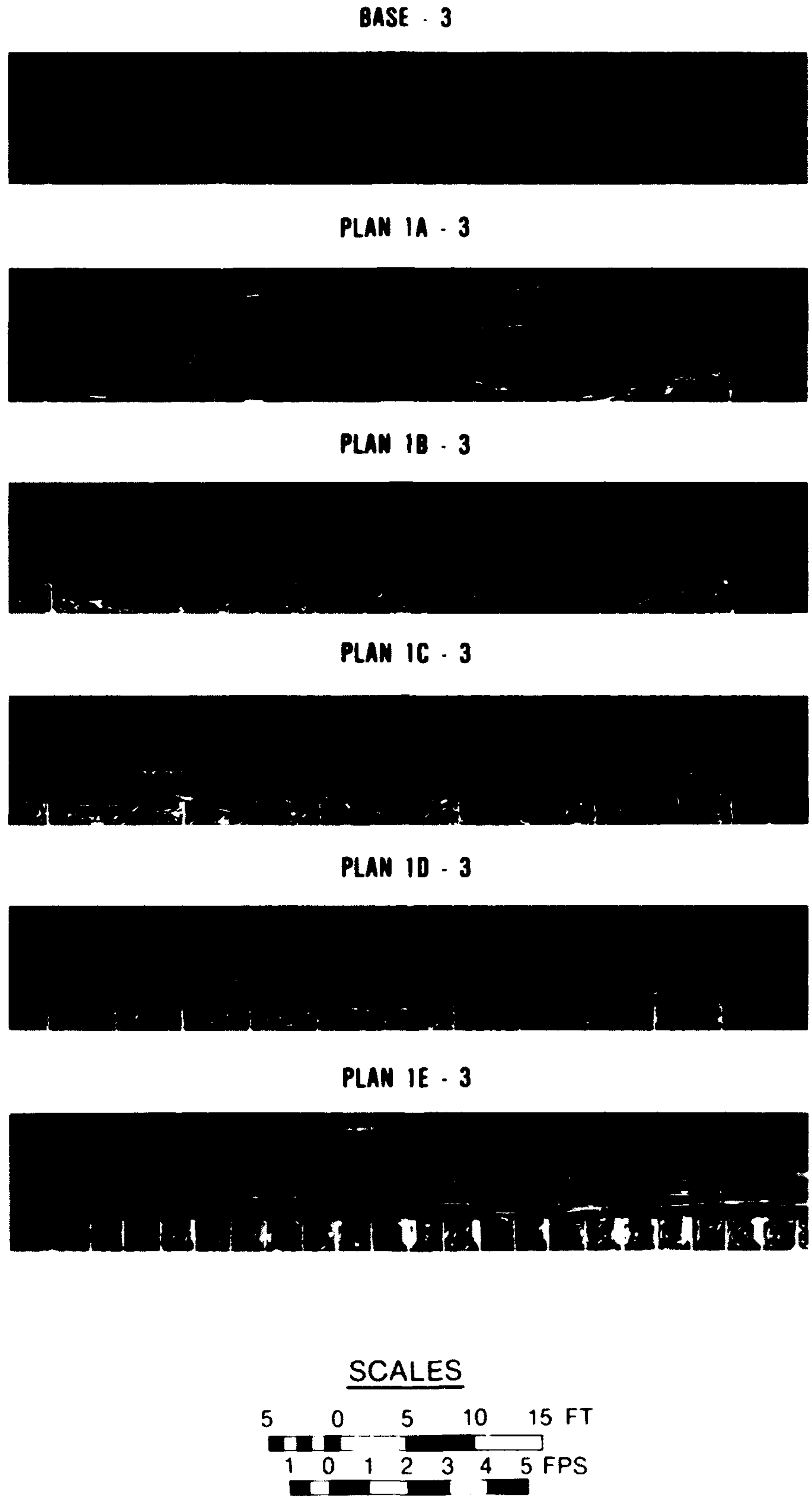


Figure 4. Surface current patterns from the Series I tests

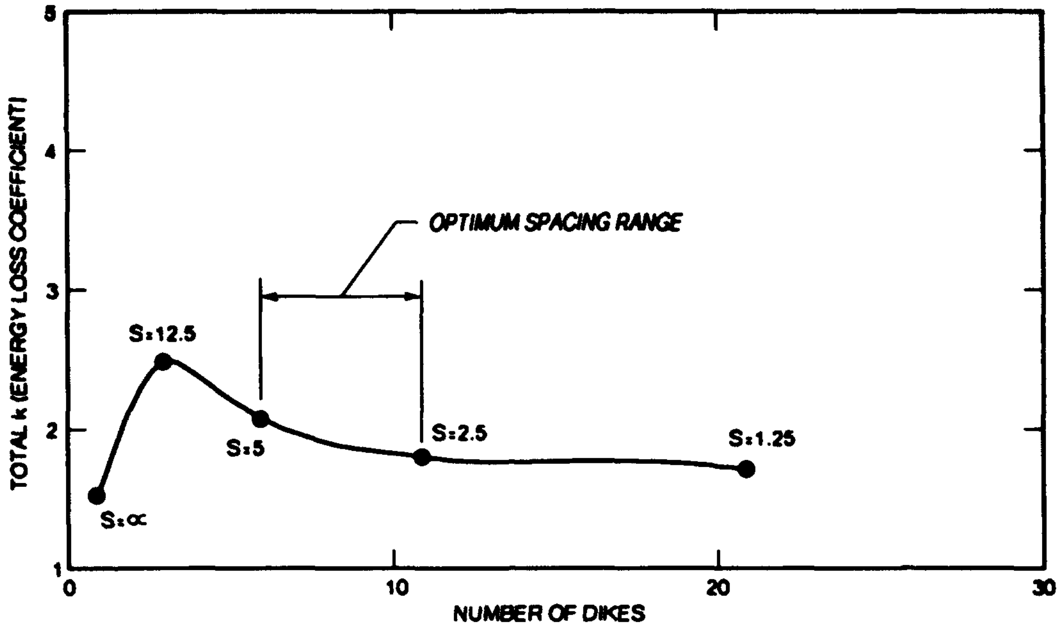


Figure 5. Total k versus number of dikes

Dike Spacing Design Equations

16. Figure 6 is a smooth exponential curve of k versus dike spacing ratio S . Equation 1 plots the curve shown in Figure 6:

$$k(s) = 0.0095(S)^{1.5509} \tag{1}$$

where k(s) is the energy loss associated with a given spacing ratio. The total energy loss for the entire dike field can be derived from Equation 1 and the following type of equation for an estuarine situation:

$$k_T = 1.5 + k(s)(\text{No. of dikes} - 1) \tag{2}$$

where k_T is the total energy loss.

17. The use of Equation 1 requires a preselected spacing ratio. The guidance in this report has defined feasible ratios between 5:1 and 2.5:1. The upper limit of 5:1 can prevent excessive energy loss and associated nonuniform velocities through the dike field. Closer spacing than 2.5:1 provides little benefit in terms of energy loss, and should generally be avoided in terms of excessive construction. The guidance presented herein targets an optimum dike spacing range and graphically displays the spacing and energy

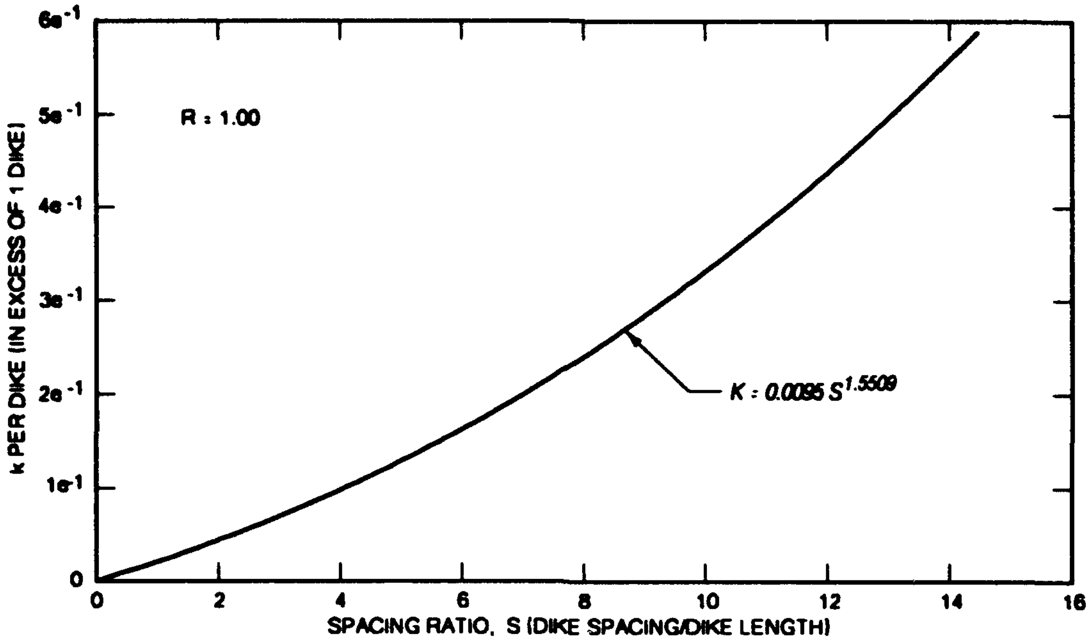


Figure 6. Energy loss per dike versus spacing ratio S

loss relationship, but still leaves a wide margin of spacings that must be refined by the designer for a given site.

Spacing Design Framework

18. To use the total loss equation for designing estuarine dike field spacing, follow these steps:

- a. Estimate the necessary velocity history required to maintain the channel. This velocity should be equivalent to any self-maintaining reach within the project or be designed to exceed the shoaling sediment transport threshold.
- b. Choose a dike spacing ratio between 2.5 and 5 (Figure 5). (This step is based on existing dike fields, designer experience, or judgment.)
- c. Estimate the dike length sufficient to reduce the channel area and provide the velocity selected in step a.
- d. Determine the number of dikes and adjusted spacing: multiply the spacing ratio (step b) by dike length (step c) to determine the actual spacing. Then divide project reach length by the spacing and add 1 dike to determine the number of dikes required. Unless an even value is obtained, round off to the nearest whole dike value and adjust spacing accordingly. Note: Do not adjust spacing outside of the suggested range of 5:1-2.5:1.
- e. Calculate the value of k per dike for this spacing from Equation 1.

f. Calculate the total energy loss coefficient k_T for the dike field from Equation 2.

g. Run a one-dimensional unsteady flow model over an appropriate time (tidal cycles) using the coefficient k_T as an expansion or contraction energy loss coefficient (see following section).

h. Compare the model results from step g with the required velocities from step a. If results are inadequate, modify length and repeat steps c through h until the necessary velocities are obtained.

Sample Application of Spacing Framework

19. Suppose a problem shoaling reach has been identified at the estuary shown in Figure 7, and a dike field was proposed as a mitigation measure.

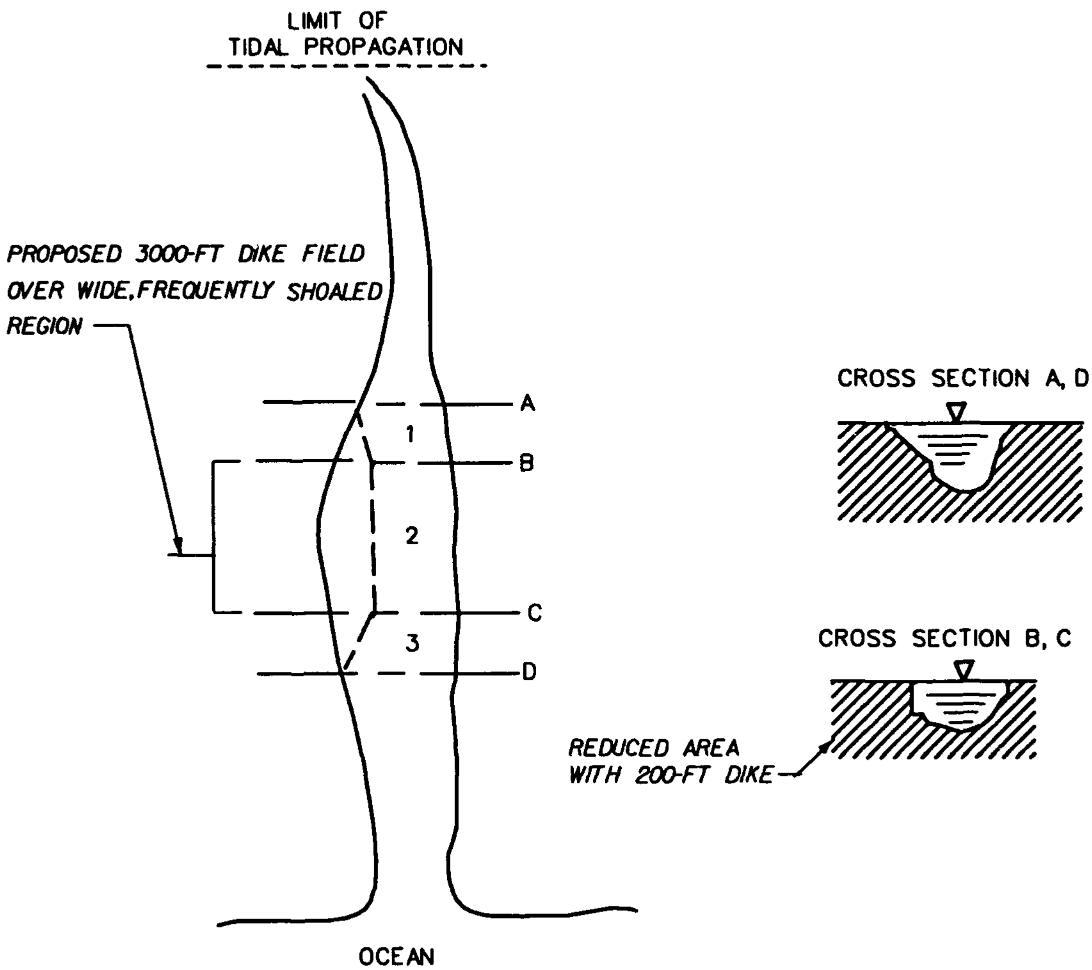


Figure 7. Example estuary with proposed dike field

Outside of the troublesome 3,000-ft region shown, channel velocities were determined sufficient to maintain the channel (Step a). An initial spacing

ratio of 3.75 was selected from the optimum range (Step b). In order to constrict the cross-sectional area in the problem reach to that of the naturally maintained channel sections, a dike length of 200 ft is necessary (Step c). The dike length results in an actual spacing of 750 ft, and five dikes are required for the 3,000-ft reach (Step d). Using Equation 1 to calculate k(s):

$$k(s) = 0.0095(3.75)^{1.5509} = 0.0738 \text{ (Step } \underline{e}\text{)}$$

and from Equation 2:

$$k_{(T)} = 1.5 + 0.0738(4) = 1.8 \text{ (Step } \underline{f}\text{)}$$

20. Using the design outline with a specific one-dimensional numerical model (Step g) requires a knowledge of how structures are accounted for in the code. Model documentation should be reviewed for this information. The model must extend between known boundary conditions to be accurate for all conditions tested. Typical boundary conditions for this case would be from the ocean to the limit of tidal propagation. A base model run should be completed prior to structure evaluation. The base run should cover at least 1-1/2 tidal cycles so that the first half tidal cycle can be discarded considering necessary adjustments during this time. Most one-dimensional codes such as DWOPER* use expansion and contraction coefficients. The design value k_T can be used directly as a contraction or expansion coefficient. The one-dimensional model UNET** requires input of a parameter < instead of contraction and expansion coefficients. These two numerical models are discussed in the following sections as they apply to the estuarine dike field evaluation such as shown in Figure 7.

21. For the example estuary and proposed dike field shown in Figure 7, the cross-sectional area narrows according to the dike length at section B. As flow moves past sections 1 and 3, the flow field contracts and enlarges according to its tidally influenced direction. In codes such as DWOPER,

---

* D. L. Fread. 1978. "NWS Operational Dynamic Wave Model, Verification of Mathematical and Physical Models," *Proceedings of 26th Annual Hydraulics Division Specialty Conference, ASCE*, College Park, MD, pp 455-464.

** R. L. Barkau. 1991 (May). "UNET: One-Dimensional Unsteady Flow Through a Full Network of Open Channels; User's Manual," Prepared for US Army Engineer Hydrologic Engineering Center, Davis, CA.

expansion and contraction coefficients would be applied at these sections. These coefficients are based on a change in flow velocity between sections. Using $k_{(T)}$ from Equation 2, a reasonable approximation would be to use $1/2k_{(T)}$ in sections 1 and 3 so that the total losses would equal the sum of $k_{(T)}$.

22. The UNET < is based on the velocity in a single segment of flow. To calculate < equivalent to $k_{(T)}$ for use with the design framework, the cross-sectional area outside the proposed dike field must be related to the numerically represented dike field cross-sectional area:

$$< = k_{(T)}[1 - (A_b/A_a)^2] \tag{4}$$

where

A_b = cross-sectional area at section B

A_a = existing cross-sectional area outside of the dike field

Then substitute < in segment 2 to evaluate the dike field.

23. Model results should then be compared with the desired velocities (Step h). Within the given range of spacings suggested in this report (5:1-2.5:1), spacing adjustment alone will not significantly affect model results. Therefore dike length should be adjusted (Step c) and the design procedure should be repeated until the required velocities are obtained. Step d allows the adjustment of spacing within the optimum range. If increasing or decreasing dike length is necessary during the design process, the adjusted spacing in Step d will also increase or decrease, respectively. It is important to note that if the adjusted spacing exceeds 5:1 or falls below 2.5:1, then these limits should be used as maximum and minimum spacing ratios, regardless of the adjusted value.

PART IV: ANGLED AND OPPOSING DIKE PLAN EVALUATIONS FROM THE SERIES II TESTS

24. The Series II test plans were designed to investigate flow field and energy loss variations by comparison to previously tested plans with the same spacing ratio. Energy loss for the Series II plans was evaluated using Figure 8, which replots the energy coefficient versus spacing ratio curve presented in Figure 6 and includes data points for the Series II tests. Flow field evaluations were based on surface current patterns.

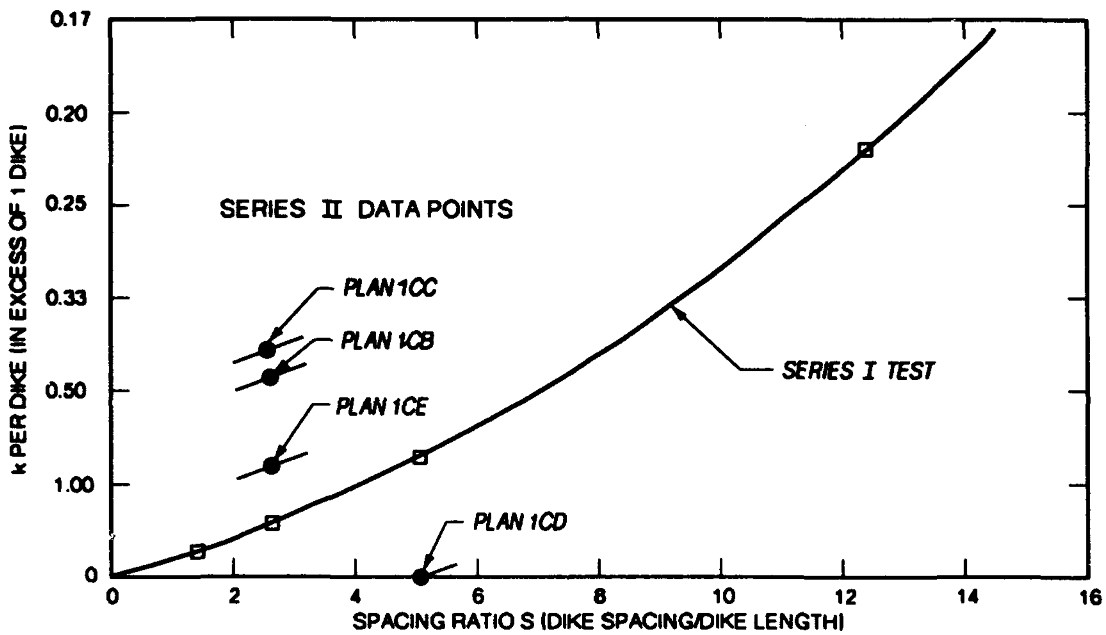


Figure 8. Energy loss per dike versus spacing with Series II test points

Angled Dike Plans

25. Figure 9 shows the current patterns around a perpendicular and an angled entrance dike in the test facility. All plans with perpendicular entrance dikes created an abrupt change in flow field as shown in Figure 9a. Figure 9b shows a smoother transition as a result of using an angled entrance dike in the test facility. A direct evaluation of energy loss can be obtained from Figure 8 by comparing the Plan 1CD energy loss coefficient with the Series I data curve from Figure 6. The Plan 1CD data point plots well below

a. Perpendicular entrance dike

b. 45-deg entrance dike

Figure 9. Flow streamlines with angled and perpendicular dike orientations

the energy loss data point for Plan 1C, with the only difference being angled entrance dikes. The angled entrance dikes provided a smoother transition into the dike field that resulted in a smaller overall dike field energy loss. A perpendicular, but shorter entrance dike might also produce a smooth and energy-efficient transition into the dike field. A shorter dike would be more cost effective for a prototype construction.

Opposing Dike Plans

26. An energy loss reduction is also seen in Figure 8 between the two Series II Plan 1CB and 1CE opposing dike plan data points. Again, with the only plan difference being the angled entrance dikes, the angled plan energy loss coefficient data point (1CE) plots well below the perpendicular entrance dike plan.

27. Opposing dikes directly opposite each other (Plan 1CB) and alternating opposing dikes (Plan 1CC) were evaluated. Figure 8 shows a smaller energy loss coefficient for Plan 1CB, indicating that a more efficient (in terms of energy loss) opposing dike field can be constructed with dikes directly across from each other.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

28. Inadequate spacing can cause one of the most costly design modifications that may become necessary during and after channel maintenance-oriented dike project construction. The amount of constriction (dike length) controls the magnitude of velocity, but spacing controls the velocity flow field through a project reach. As shown in Figure 4 (and more extensively in Ashley and Brogdon*), the plans having the highest spacing ratios and greater energy losses also resulted in flow patterns that wove in and out around the dikes. This flow pattern caused higher velocities at certain points and slower velocities at other points along the model project reach. In a prototype, this situation can result in scour and deposition patterns within a project reach as the flow seeks equilibrium. The dike spacing design equation presented in paragraph 16 and the spacing design procedure presented in paragraph 18 provide the basis for an efficient design for channel maintenance.

Recommendations

29. Channel constriction projects should result in a higher but uniform velocity flow field through the project reach. Engineering judgment, designer experience, and model evaluations are all important design tools. Numerical model evaluations, in accordance with the design steps in this report, are recommended for lateral dike spacing designs in estuarine or other applicable channels. Based on the subject data and testing limitations discussed, the dike length/channel width ratio (1/5) should be comparable to project conditions when applying the design steps.

30. Above- and below-project water level changes and/or changes in duration of water levels may result from the energy loss associated with dike fields. Investigating these effects is necessary to evaluate material deposition and other effects outside the project area. These situations should be considered during the design process so that they can be included within the overall maintenance plan.

---

* Op. cit.

31. Although limitations are associated with applying flume analyses to a prototype, much can be learned from continued dike plan evaluations in a controlled testing environment. Future dike plan tests should include the following:

a. Entrance dikes that are shorter but perpendicular, as opposed to angled entrance dikes. Similar energy loss and flow transition may be realized at significant construction savings.

b. Varying the ratio of dike length to channel width. This would clarify the point at which opposite bank effects can occur.

c. Evaluating submerged dike fields.

APPENDIX A: VELOCITY AND WATER LEVEL CHANGE DATA

This appendix contains the center-line test section velocity plots and water level change data as follows:

a. Figures A1-A3: Normalized center-line velocity plots for the Series I tests.

b. Figures A4-A6: Water level change plots for the Series I tests.

c. Figures A7-A9: Normalized center-line velocity plots for the Series II tests.

d. Figures A10-A12: Water level change plots for the Series II tests.

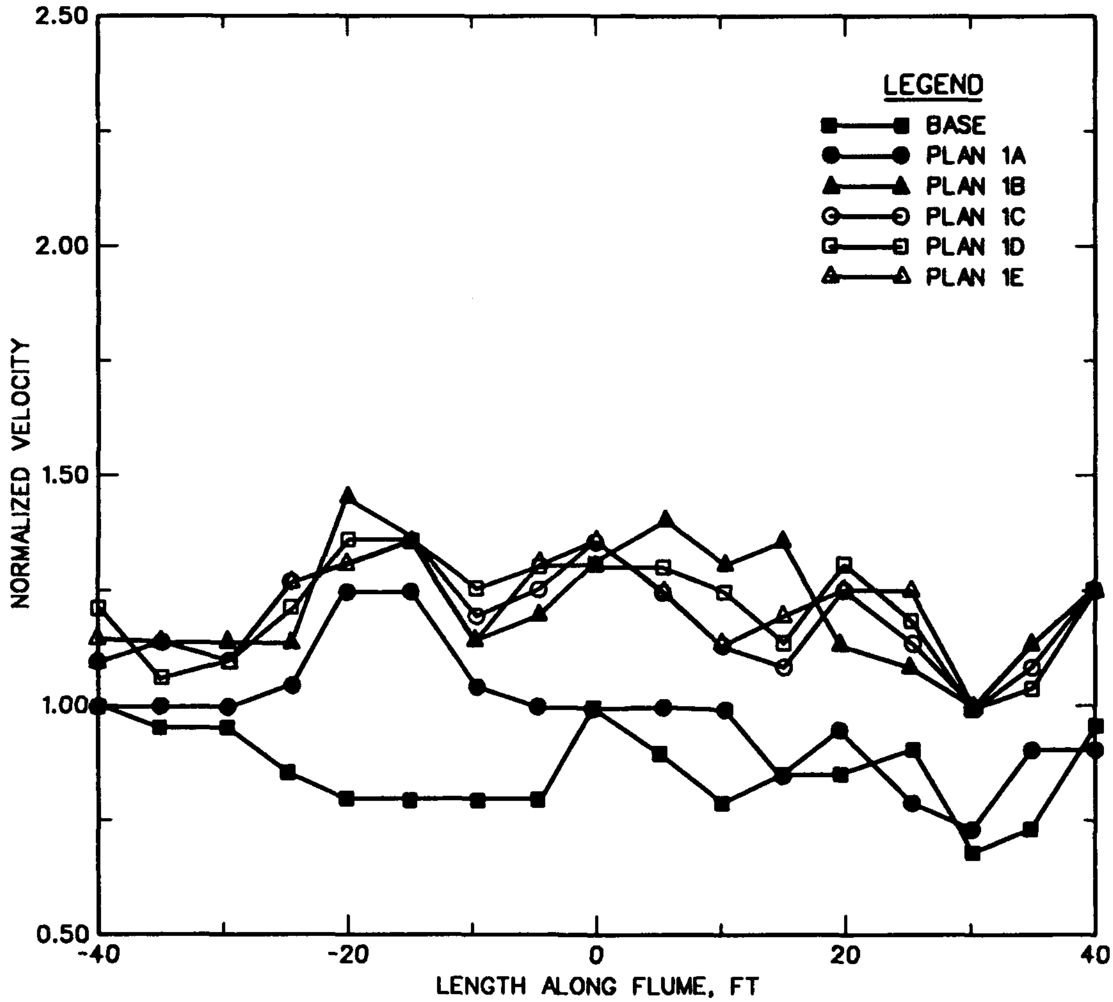


Figure A1. Center-line velocity plots for the Series I tests, 1 cfs

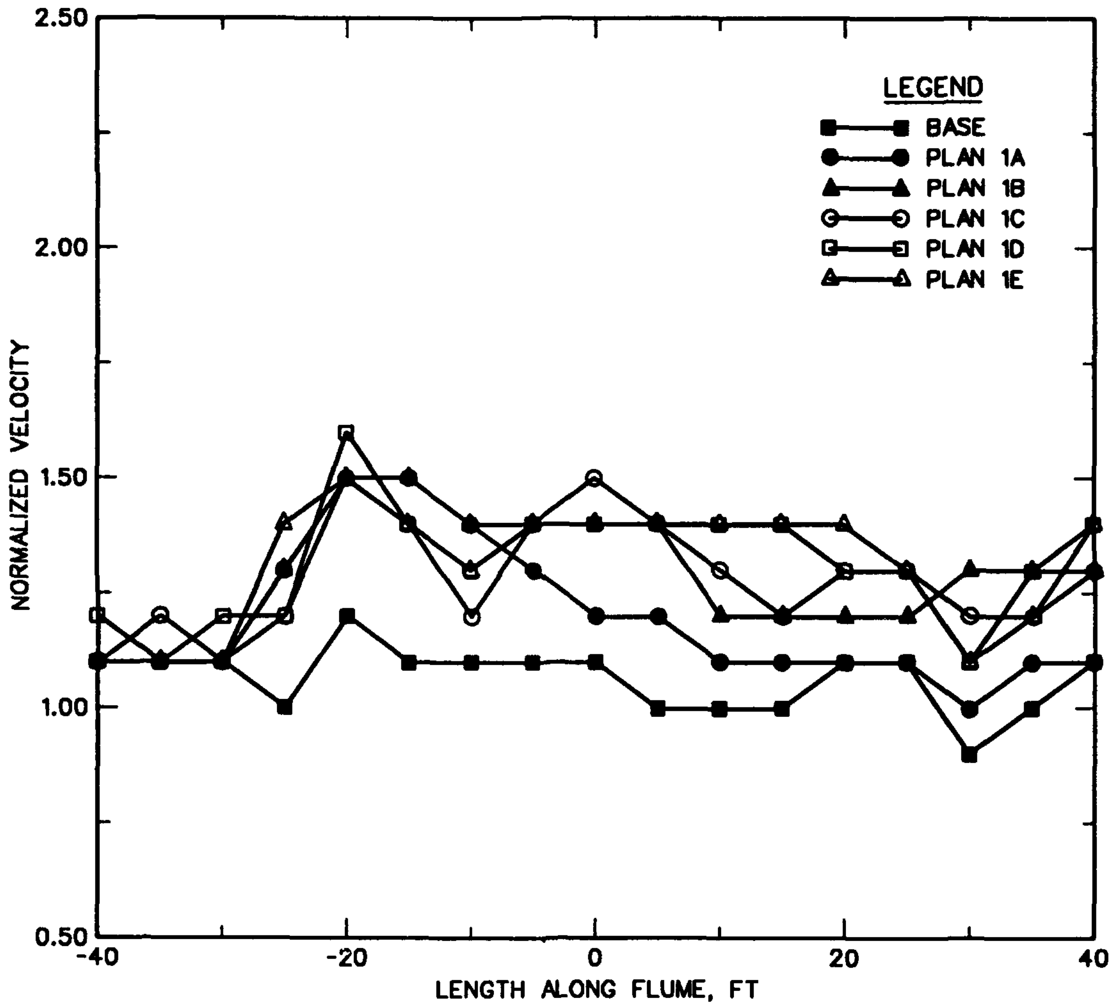


Figure A2. Center-line velocity plots for the Series I tests, 2 cfs

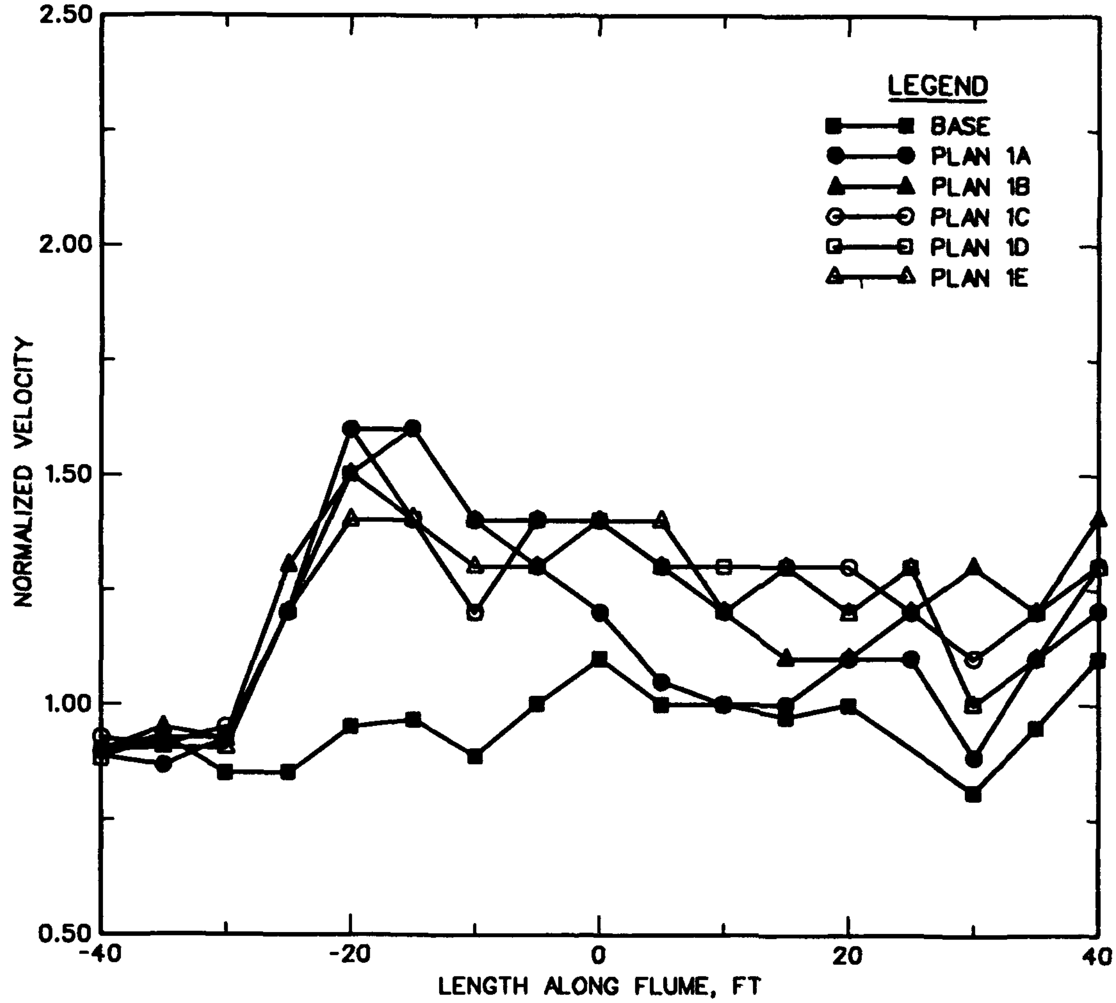


Figure A3. Center-line velocity plots for the Series I tests, 3.6 cfs

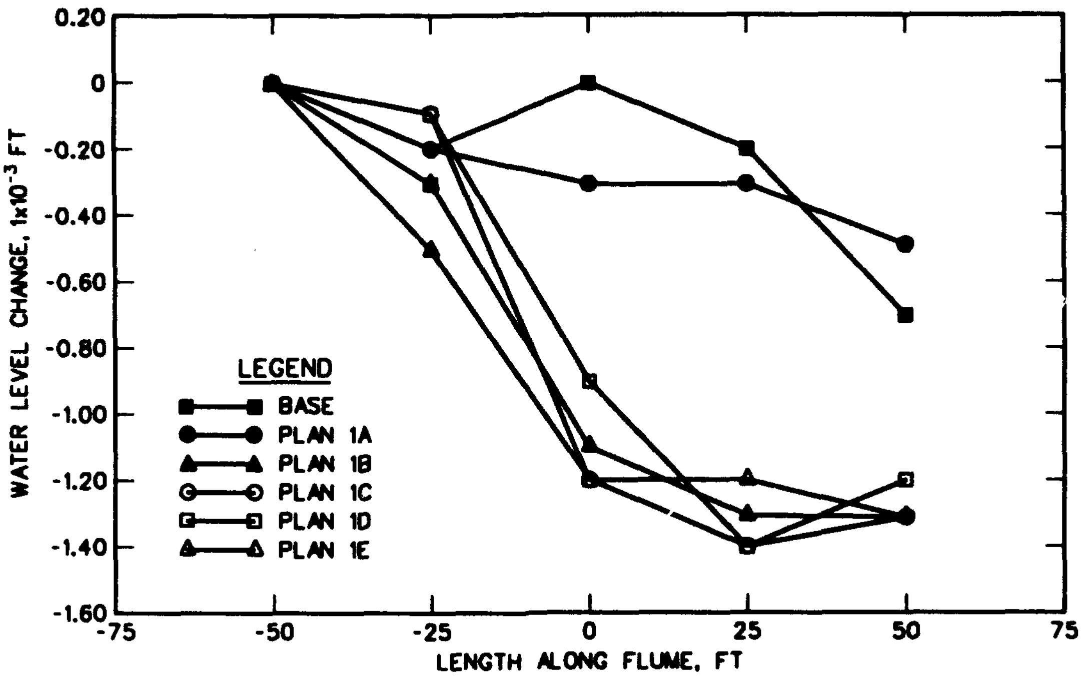


Figure A4. Water level change for the Series I tests, 1 cfs

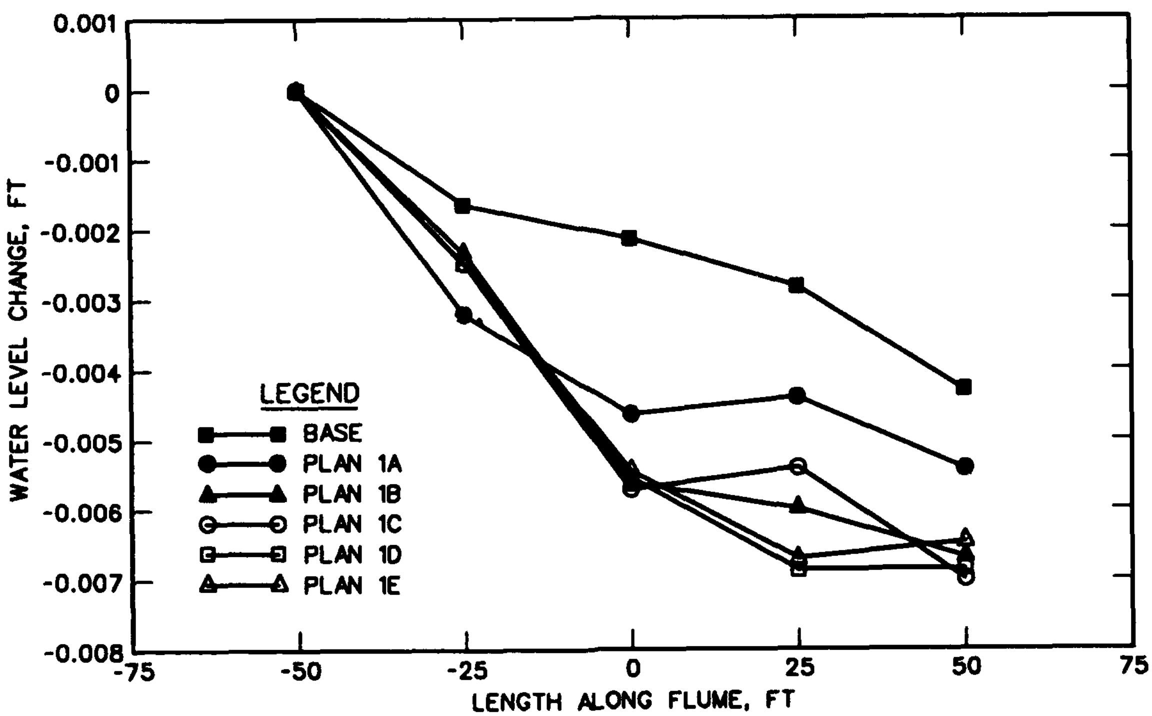


Figure A5. Water level change for the Series I tests, 2 cfs

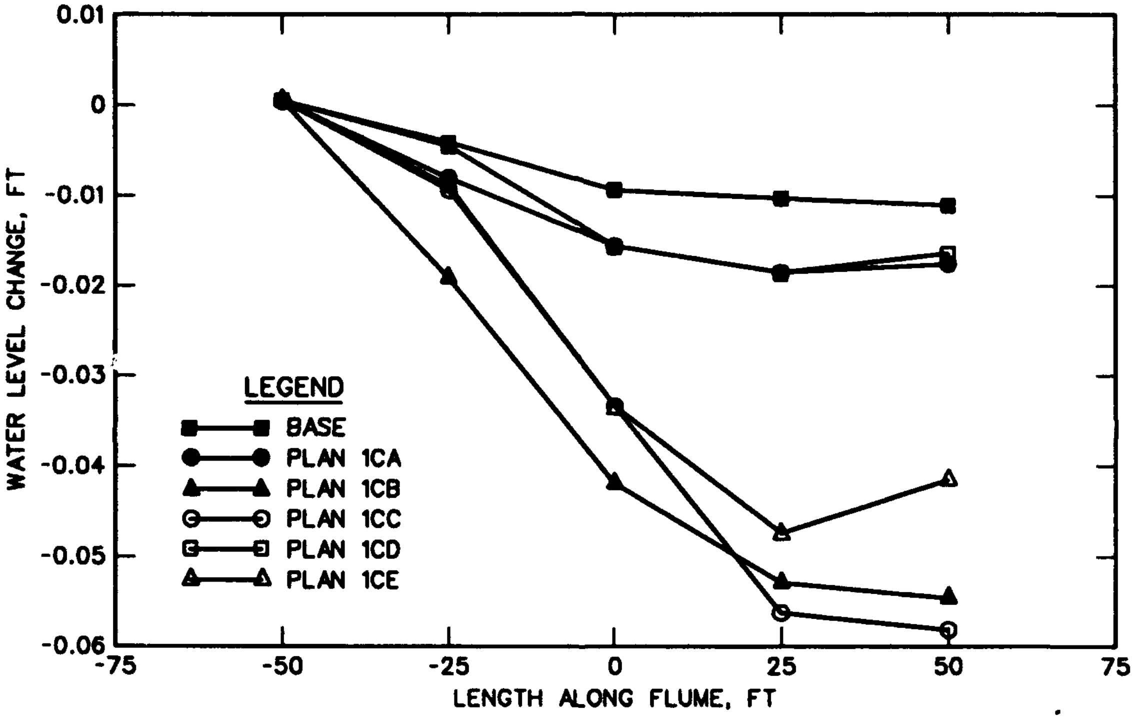


Figure A6. Water level change for the Series I tests, 3.6 cfs

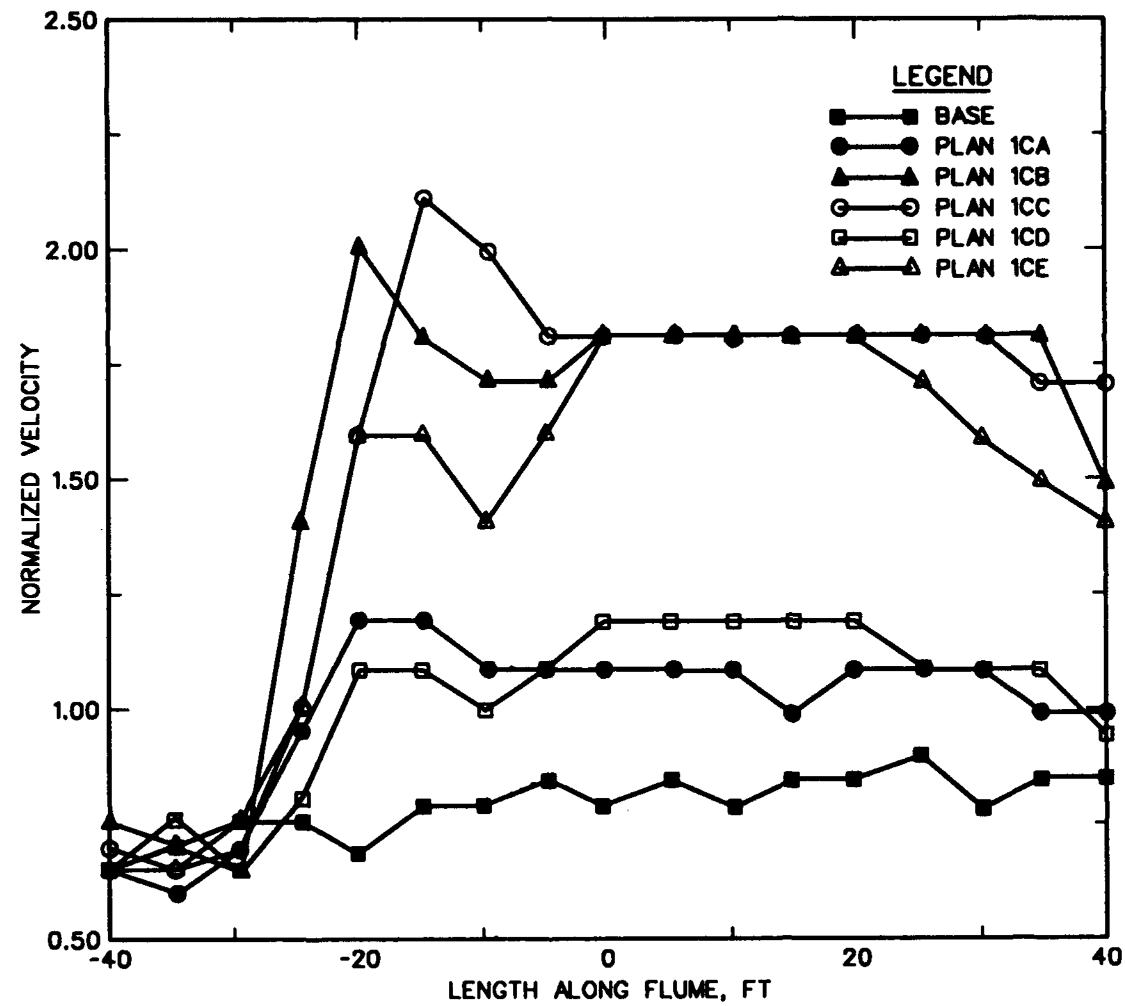


Figure A7. Center-line velocity plots for the Series II tests, 1 cfs

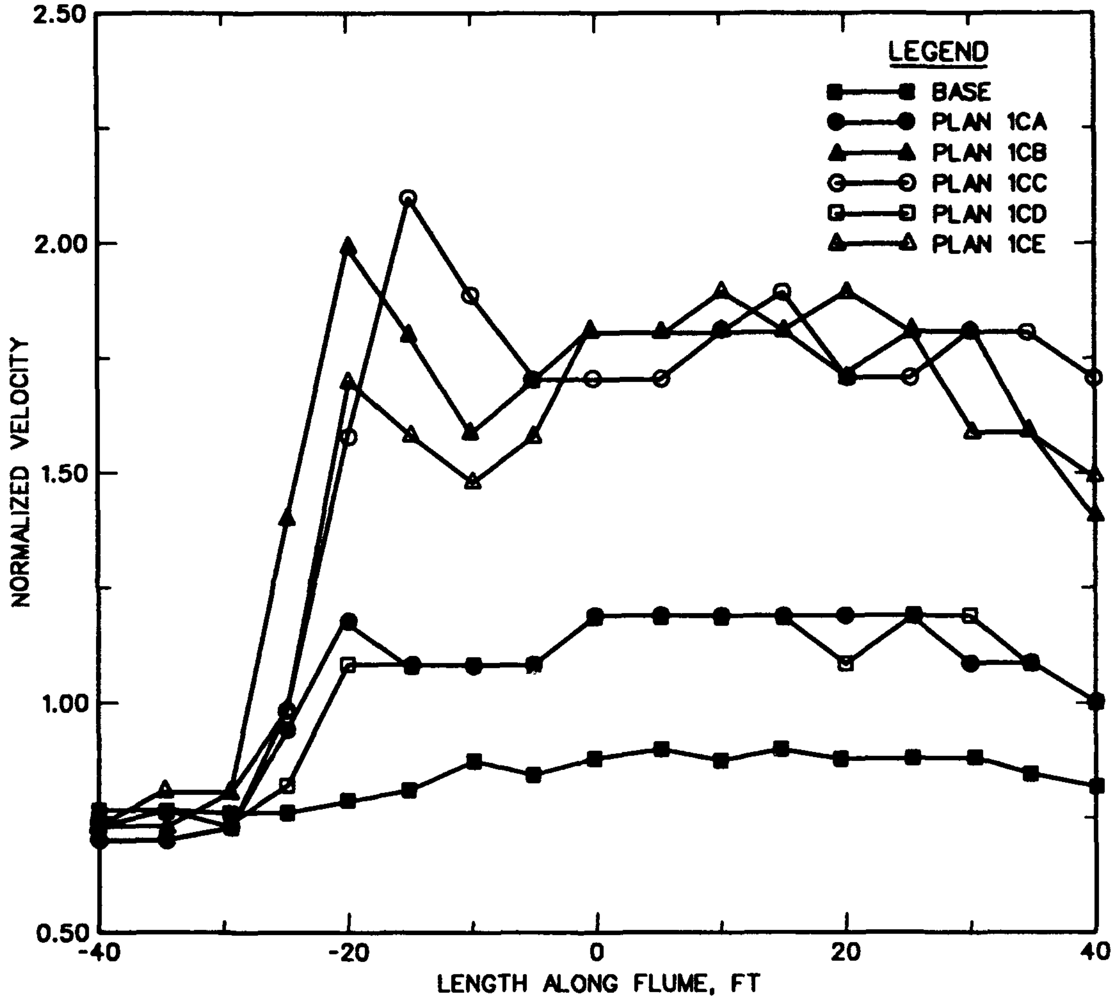


Figure A8. Center-line velocity plots for the Series II tests, 2 cfs

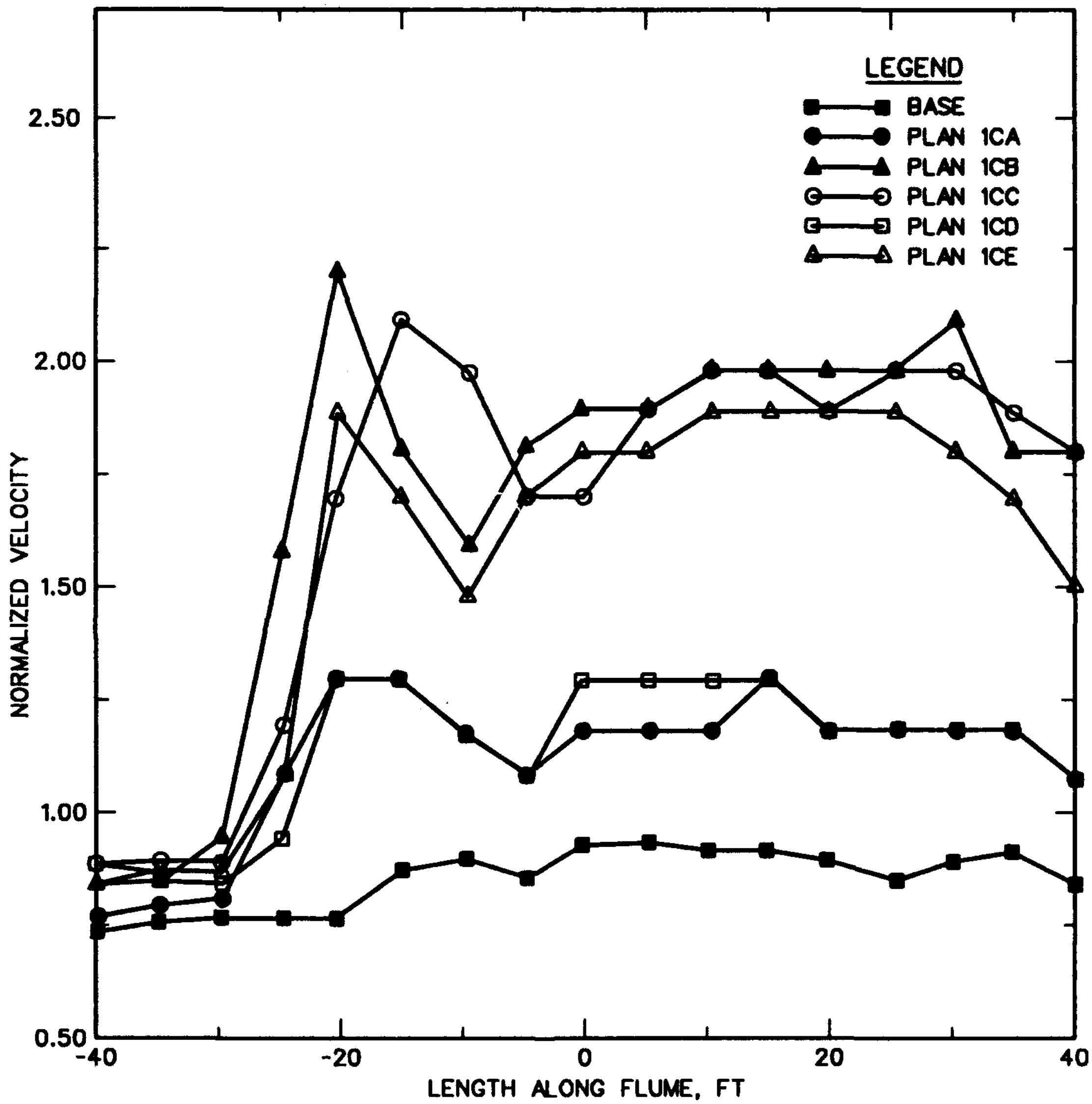


Figure A9. Center-line velocity plots for the Series II tests, 3.6 cfs

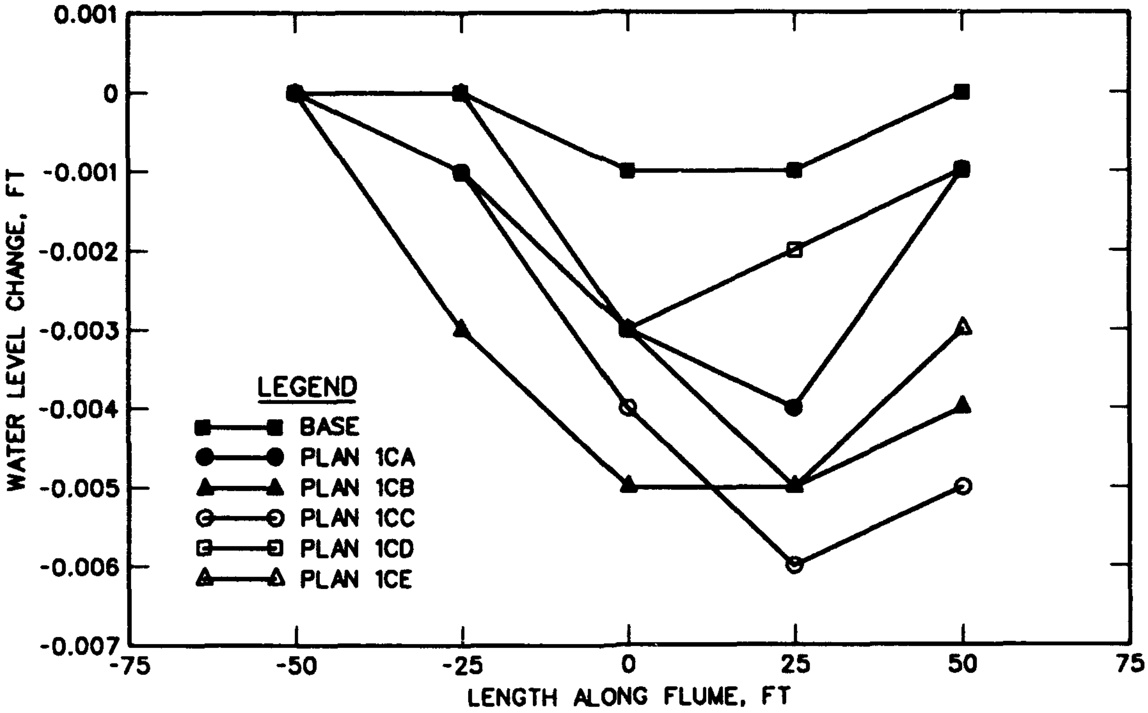


Figure A10. Water level change for the Series II tests, 1 cfs

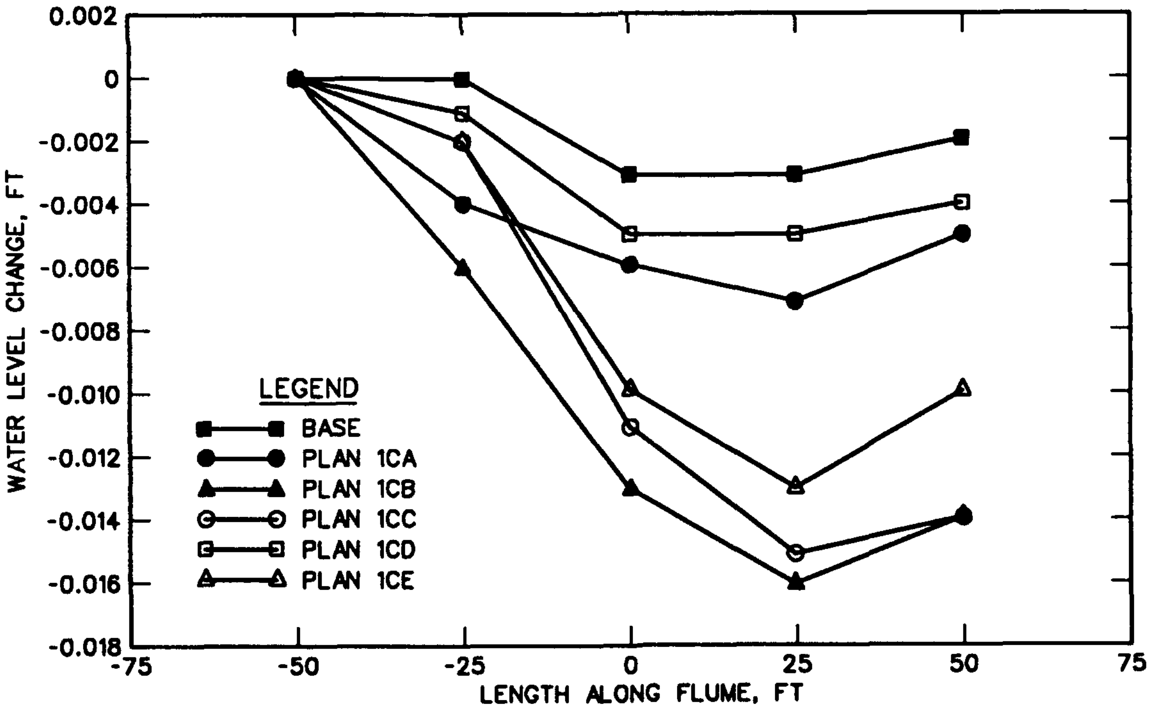


Figure A11. Water level change for the Series II tests, 2 cfs

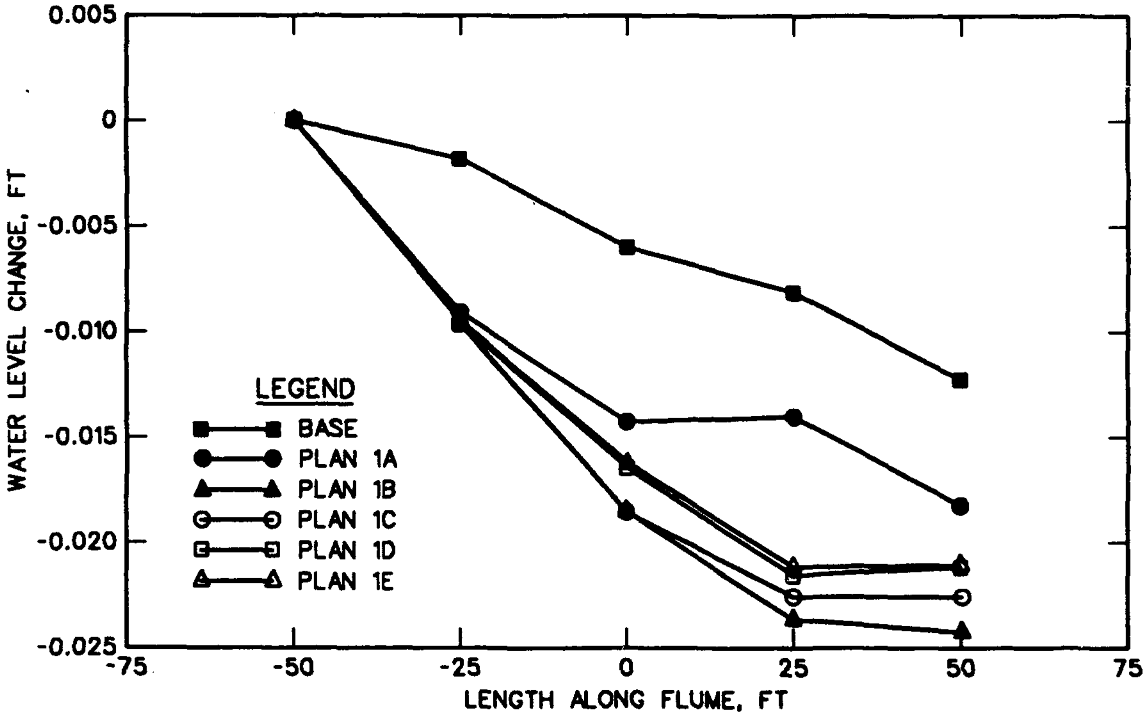


Figure A12. Water level change for the Series II tests, 3.6 cfs

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1993

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Design Criteria for Lateral Dikes in Estuaries

5. FUNDING NUMBERS
WU 32655

6. AUTHOR(S)
R. C. Berger
M. P. Alexander

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station, Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report REMR-HY-9

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers, Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
A report of the Hydraulics Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) research program. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Guidelines for lateral dike spacing were developed at the US Army Engineer Waterways Experiment Station. The guidance was based on laboratory flume analyses and applies to dikes designed for channel maintenance. Various dike plans were tested to develop energy loss versus dike length-to-spacing relationships, and spacing guidelines are presented in the form of a design outline. The testing program also included alternating dikes versus dikes positioned directly across from each other in the flume channel test section and angled dike field entrance dikes as an energy loss reduction measure.

14. SUBJECT TERMS
Dike spacing
Estuaries
Lateral dikes
Navigation maintenance
Training structures

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		